AIRS/AMSU/HSB Version 5 Level 2 Product Levels, Layers and Trapezoids

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A Discussion of the AIRS Level 2 Products Levels, Layers and Trapezoids and Top of Atmosphere and the Surface in Product Profiles

Introduction

In this documentation, names in bold are fields in the AIRS product files.

Please note in the discussion which follows, non-profiles are swath data fields dimensioned (**GeoXTrack**[30 elements], **GeoTrack**[45 elements]). The level quantity profiles of the Standard Product are dimensioned (**StdPressureLev**[28], **GeoXTrack**[30], **GeoTrack**[45]) and the layer quantity profiles are dimensioned (**StdPressureLay**[28], **GeoXTrack**[30], **GeoTrack**[45]). On the other hand, the level quantity profiles of the Support Product are dimensioned (**XtraPressureLev**[100], **GeoXTrack**[30], **GeoTrack**[45]) and the layer quantity profiles are dimensioned (**XtraPressureLay**[100], **GeoXTrack**[30], **GeoTrack**[45]).

Pressure Grids, Surface Pressure and Bottom Element of Profiles

The surface pressure, **PSurfStd**, is derived from the NCEP GFS 3-, 6- and 9-hour forecasts of surface pressure and the topography provided by a digital elevation model (DEM):

$$\mathbf{PSurfStd} = \mathbf{P_F} \times \left[1 - \frac{(\mathbf{h} - \mathbf{h_F})}{\mathbf{c_p T_s}}\mathbf{g}\right]^{7/2}$$

where $\mathbf{P_F}$ is the forecast surface pressure; **h** is the altitude from the DEM; $\mathbf{h_F}$ is the forecast altitude; $\mathbf{T_s}$ is the forecast surface temperature; $\mathbf{c_p}$ is the gas constant; **g** is the gravitational constant. The forecast surface pressure is interpolated to the AMSU FOV centriod, and the elevation is the average over the DEM within the AMSU FOV.

The fixed pressure grid for the AIRS Level 2 Standard Temperature Product, **pressStd**, contains 28 levels defined congruent with the World Meteorological Organization (WMO) standard pressure levels. Thus the highest pressure in the array is the <u>first</u> element. The 17 WMO standard pressures are a subset of this pressure array. The level spacing is closer together in the lower atmosphere. The units are mb. See **V5_L2_Standard_Pressure_Levels.pdf** for a table of the pressure level array, **pressStd**.

The standard product profiles are filled, <u>decrementing</u> indices from the top of atmosphere (TOA), array element 28, to the near-surface array element at (1-based) index **nSurfStd**. This bottom level is below the surface topography unless the pressure at the surface is within 5 mb of the pressure of the next **pressStd** level upward. In that case, **nSurfStd** is the index of that level and is above the surface. Entries in standard product profiles whose indices are less than this index must be ignored. They are customarily set to –9999.

The fixed pressure grid for the AIRS Level 2 Support Product, **pressSupp**, contains 100 levels, and is the pressure grid used by the AIRS rapid transmittance algorithm (RTA) to calculate radiances. The order of pressures is reversed from that of **pressStd**, i.e. the first pressure is at the TOA. The order and finer grid were defined to facilitate diagnosis of the retrieval process and calculation of radiances from the retrieved physical products. Thus the highest pressure in the array is the last element. The level spacing is closer together in the lower atmosphere. The units are mb. See **V5_L2_Support_Pressure_Levels.pdf** for a table of the pressure level array, **pressSupp**.

The support product profiles are filled, incrementing indices from the TOA, array element 1, to the near-surface array element at (1-based) index **nSurfSup**. This bottom level is below the surface topography unless the pressure at the surface is within 5 mb of the pressure of the next **pressSupp** level upward. In that case, **nSurfSup** is the index of that level and is above the surface. Entries in support product profiles whose indices are greater than this index must be ignored. They are customarily set to diagnostic intermediary values during the retrieval process, and are not physically meaningful.

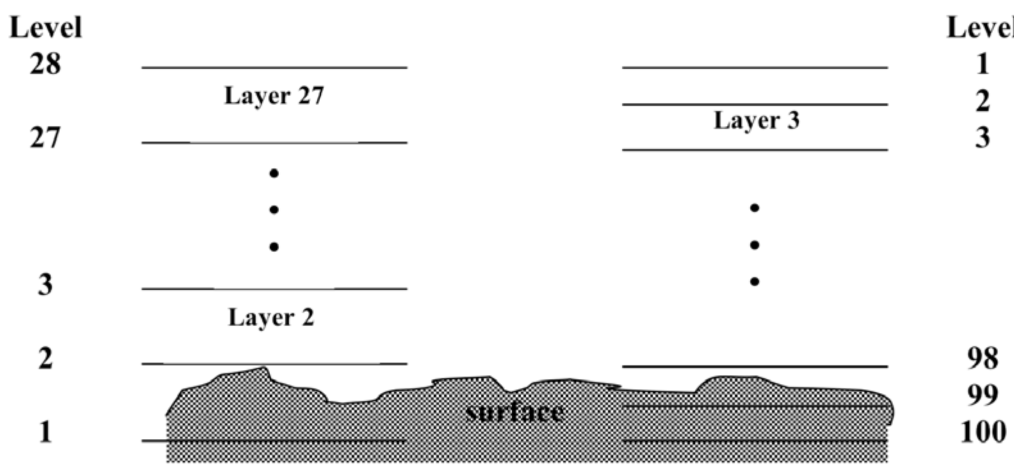

Figure 1: Layout of pressStd and pressSupp levels.

If the surface topography is within 5 mb of **pressStd** level index 2, then **nSurfStd** = 2; otherwise **nSurfStd** = 1 in this example.
Similarly, if the surface topography is within 5 mb of **pressSupp** level index 98, then **nSurfSup** = 98; otherwise **nSurfSup** = 99 in this example.

A table of the pressure values for the **pressStd** array is provided in **V5_L2_Standard_Pressure_Levels.pdf**. A table of the pressure values for the **pressSupp** array is provided in **V5_L2_Support_Pressure_Levels.pdf**.

Trapezoidal Layers

A new concept, trapezoidal layers, is introduced in V5 to support associated averaging kernels, verticality and degrees of freedom of retrieved constituents. They define the bounds upon which the IR retrieved layer quantity mixing ratios of CO, CH_4 and O_3 are defined which are associated with the kernels, verticality and degrees of freedom.

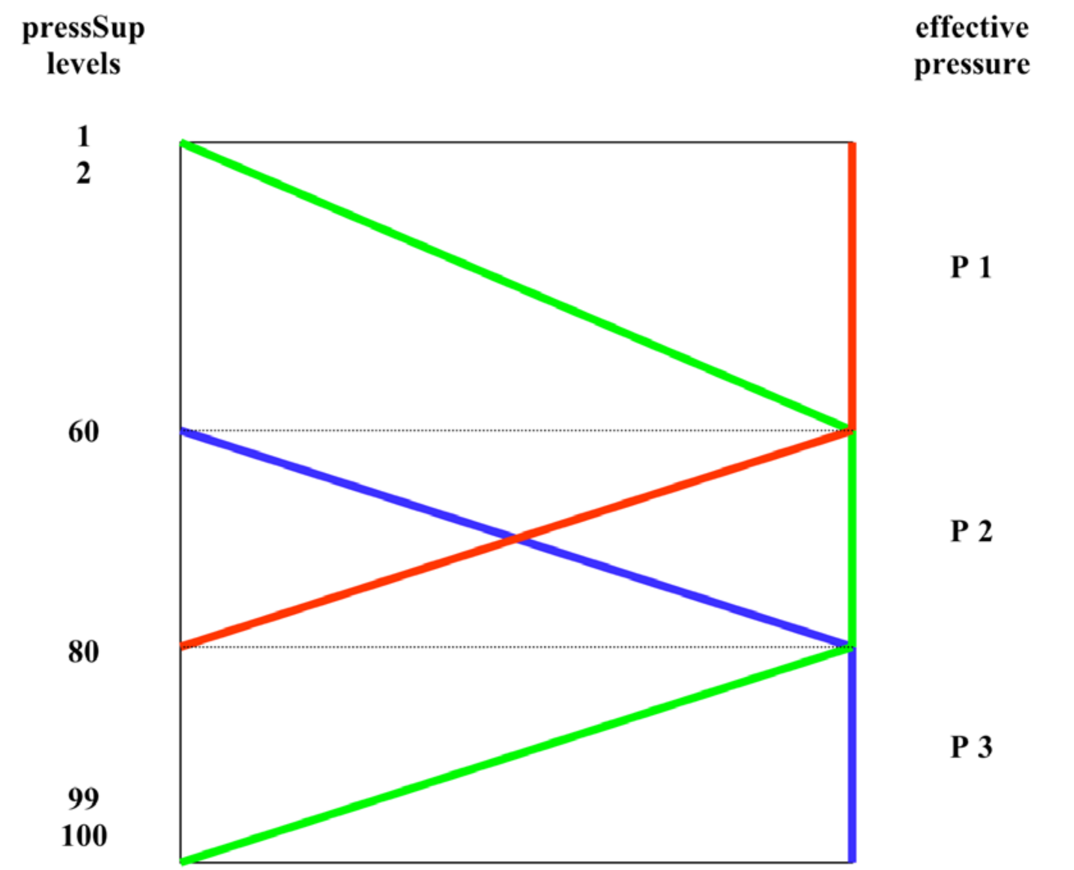

Figure 2: Schematic of a three-trapezoid profile for constituent XX.

The trapezoids are defined by the array, **XX_trapezoid_layers**, which contains the 1-based indices of the **pressSupp** profile containing the relevant pressures. The effective pressures of the trapezoidal layers, **XX_eff_press**, are given in millibar. Thus in this example for constituent XX, **XX_trapezoid_layers** = [1,60,80] and **XX_eff_press** = [P 1, P 2, P3]. The constituent volume mixing ratio, **XX_VMR_eff**, is also a 3-element array. The bottom trapezoid face is always terminated at the surface.

The number of trapezoids depends upon the constituent being retrieved. The sides of the trapezoids drop off from the face linearly in log(p), dropping to zero at the pressure level of the most distant vertex of the adjacent trapezoid face. The lowest altitude trapezoid drop off terminates at the surface and the highest altitude trapezoid drop off terminates at the top of the atmosphere. **XX_VMR_eff** is computed from the integrated column density for each trapezoidal layer, and is reported at the effective pressure, **XX_eff_press**, of the layer. **XX_eff_press** is defined as the pressure weighted center of the layer. Layers below the surface are filled with -9999. The value quoted on the lowest layer above the surface is the mean volume mixing ratio in the layer bounded by the next higher level and the surface.

XX_total_column is the integrated column amount of XX from the top of the support product atmosphere (0.005 mb) to the surface. It is computed by summing the 100 column density values, **XXCDsup**, contained in the AIRS Level 2 Support Product file, with the appropriate weighting applied to the bottom layer that contains the surface. Layers below the surface are not included in the sum.

XX_dof provides a measure of the amount of information in the constituent retrieval. It is computed by summing the diagonal elements of the averaging kernel, **XX_avg_kern**, stored in the AIRS Support Product files. Profiles for which **XX_dof** < 0.4 indicates little information in the retrieval comes from the measured radiances. Profiles for which 0.5 > **XX_dof** > 0.4 should be used with great caution.

XX_verticality is a vector computed by summing the rows of **XX_avg_kern**. Our code sums the columns since the AIRS averaging kernel is symmetric. The peak of **XX_verticality** indicates the vertical location of the maximum sensitivity of the constituent product and the magnitudes of **XX_verticality** are a rough measure of the fraction of the retrieval determined from the data as opposed to the first guess. Values near unity should be considered highly determined from the measurement, while smaller values indicate the retrieval contains a large fraction of the first guess. Verticality values are sometimes less than zero, especially for the lowest and highest trapezoids.

The problem with associating the verticality with a total column averaging kernel is that it neglects the fact that the retrieval can only move as superpositions of the trapezoids. Convolution using the verticality alone will not account for the possibility that the “independent constituent profile” contains structure that the trapezoids can or cannot resolve. Bearing this caution in mind, a researcher convolving an independent profile to the AIRS measurement space must perform the calculation:

$$X' = X_0 + FAF'(X - X_0)$$

where:

X_0 = first guess profile on 100 AIRS layers

X' = convolved independent profile on NSurfSup AIRS layers

$F = N \times \text{NSurfSup}$ matrix of trapezoids

$A = N \times N$ averaging kernel matrix

$F' = \left[F^T F\right]^{-1} F^T$ = pseudo-inverse of F

Each column of F represents one of the N trapezoids on the AIRS 100 layer grid, starting from the top trapezoid to the bottom. Comparisons can then be made between the AIRS retrieved 100 layer profile found in the AIRS Level 2 Support Product and the convolved independent profile, X'.

For the AIRS constituent retrievals (H_2O, CO, CH_4 and O_3) use the logarithm of the profile column density in place of the column density, i.e., use log(**XXCDsup**) instead of **XXCDsup** in this calculation.

We recommend that the interested user see the paper:

E. Maddy et al. (2007), Vertical Resolution Estimates in Version 5 of AIRS Operational Retrieval, IEEE TGARS.

Temperature Profiles

The standard product temperature profile, **TAIRStd**, and the support product temperature profile, **TAIRSup**, are both level quantities, i.e. they are the retrieved air temperature at the corresponding pressure level. **TAIRStd** is reported on the **pressStd** levels and **TAIRSup** is reported on the **pressSupp** levels. The pressure arrays appear once per granule as attributes rather than being replicated 1350 times as full swath arrays. They are listed for convenience in the two documents:

V5_L2_Standard_Pressure_Levels.pdf
V5_L2_Support_Pressure_Levels.pdf

Both temperature profiles vary linearly between levels, and **TAIRStd** is obtained from **TAIRSup** using linear interpolation with pressure. The surface air temperature, **TSurfAir**, is then obtained from the support product temperature profile, also using linear interpolation with pressure.

Let:

$$\mathbf{f} = \frac{\mathbf{PSurfStd} - \mathbf{pressSup}[\mathbf{nSurfSup}]}{\mathbf{pressSup}[\mathbf{nSurfSup} - 1] - \mathbf{pressSup}[\mathbf{nSurfSup}]}$$

The surface air temperature at **PSurfStd** is:

$$\mathbf{TSurfAir}_{\mathbf{PsurfStd}} = \mathbf{f} \times \mathbf{TAIRSup}[\mathbf{nSurfSup} - \mathbf{1}] + (\mathbf{1} - \mathbf{f}) \times \mathbf{TAIRSup}[\mathbf{nSurfSup}]$$

Moisture Profiles

All moisture profiles in the standard and support products are layer quantities. Except at the top of the atmosphere, they are the mean for a layer whose bottom boundary is the pressure level at which they are reported and whose top boundary is the pressure level immediately above. See **V5_L2_Standard_Pressure_Levels.pdf** for a table of the pressure level array, **pressH2O**.

The standard product moisture profile, **H2OMMRStd**, and its associated estimated error, **H2OMMRStdErr**, are both the mean mass mixing ratio in gm/kg_dry_air between adjacent **pressH2O** levels. For **14 > J ≥ nSurfStd**, the value at level **J** is the mean mixing ratio between level **J** and **J+1**. For **J=15**, the value is the mean over the layer bounded by that pressure level (50 mb) and the TOA of the support product (0.005 mb). The mean mixing ratio in the layer bounded by the surface is equal to mixing ratio at **nSurfStd**.

The support product moisture profile, **H2OCDSup**, is the layer amount in molecules/cm^2 between **pressSupp** levels. For **2 < J < nSurfSup**, the value at level **J** is the amount between level **J** and level **J-1**. The value at **J=1** is the layer amount between that pressure level (0.0161 mb) and the TOA, 0.005 mb. The values of **H2OCDSup** below **nSurfSup** are zero and the value at **PSurfStd** must be interpolated or extrapolated in pressure to arrive at the amount from the surface up to level **nSurfSup -1**.

The value of **H2OCDSup** at the surface (at **PSurfStd**) is thus:

$$\mathbf{H2OCDSup_{PsurfStd} = f \times H2OCDSup\left[nSurfSup - 1\right] + \left(1 - f\right) \times H2OCDSup\left[nSurfSup\right]}$$

The retrieval algorithms use linear interpolation in pressure for the surface layer, which is equivalent to constant mass mixing ratio in this level.

H2OMMRSat_liquid and **H2OMMRSat** both provide profiles of the integrated mass of water vapor in saturated equilibrium between **pressH2O** levels divided by the integrated mass of dry air. **H2OMMRSat_liquid** assumes equilibrium with liquid water. **H2OMMRSat** is in equilibrium with ice so long as the **TAirSup** (100 level profile) exceeds 273.15 K. If **TAirSup** drops below that threshold, the saturation calculation shifts to that over liquid water. Thus within a layer in which the temperature crosses 273.15 K, the calculation will shift between saturation over ice to that over liquid to derive its integrated mass of water vapor. Near the surface the two saturation profiles are identical, but they will diverge in the case that the temperature profile crosses the threshold. The constituent relationship employed is that of Murphy and Koop (2005).

Important note: The V4 saturation mixing ratio was calculated at the temperature of the standard pressure levels using Buck (1981). The calculation took into account the shift from liquid to ice at 273.15 K, but the saturation profile was not an integration over each layer. Instead, it was a level quantity at the standard pressure levels. It could not be directly compared to the observed moisture profile, which was a layer quantity. Doing so would result in absurd estimates of relative humidity, the most benign effect being a dry bias.

Buck, A. L. (1981), New equations for computing vapor pressure and enhancement factor, J. Appl. Meteorol., 20, 1527-1532.

Murphy, D. M. and T. Koop (2005), Review of the vapour pressures of ice and supercooled water for atmospheric applications, Quart. J. Royal Met. Soc, 608 Part B, 1539-1565.

Ozone Profiles

The standard product and support product ozone profiles are all <u>layer quantities</u>. Except at the top of the atmosphere, they are the mean for a layer whose bottom boundary is the pressure level at which they are reported and whose top boundary is the pressure level immediately above.

The standard product ozone profile, **O3VMRStd**, and its associated estimated error, **O3VMRStdErr**, are the mean volume mixing ratio in molecules/molecules_dry_air between **pressStd** levels. For **28 > J ≥ nSurfStd**, the value at level **J** is the mean mixing ratio between level **J** and **J+1**. For **J=28**, the value is the mean over the layer bounded by that pressure level (0.1 mb) and the TOA of the support product (0.005 mb). The mean mixing ratio in the layer bounded by the surface is equal to mixing ratio at **nSurfStd**. **O3VMRStd** and **O3VMRStdErr** may be converted to parts per billion by volume (ppbv) simply by multiplying by 10^9.

The support product ozone profile, **O3CDSup**, is the layer amount in molecules/cm^2 between **pressSupp** levels. For **2 < J < nSurfSup**, the value at level **J** is the amount between level **J** and level **J-1**. The value at **J=1** is the layer amount between that pressure level (0.0161 mb) and the TOA, 0.005 mb. The values of **O3CDSup** below **nSurfSup** are zero and the value at **PSurfStd** must be interpolated or extrapolated in pressure to arrive at the amount from the surface up to level **nSurfSup -1**.

The value of **O3CDSup** at the surface (at **PSurfStd**) is thus:

$$\mathbf{O3CDSup_{PsurfStd} = f \times H2OCDSup\left[nSurfSup - 1\right] + \left(1 - f\right) \times O3CDSup\left[nSurfSup\right]}$$

The retrieval algorithms use linear interpolation in pressure for the surface layer, which is equivalent to constant volume mixing ratio in this level.

Ozone Trapezoidal Profile

See the discussion in the section, "Trapezoidal Layers", above. Replace XX with O3 in that text.

The AIRS standard O_3 product is a product of the IR stage of the combined IR/MW retrieval. **O3_VMR_eff** is the retrieved volume mixing ratio (ratio of number of O_3 molecules to the number of molecules of air in a unit volume) for a layer defined by the faces of the O_3 trapezoidal retrieval function. The boundaries of the faces of these layers are specified in **O3_trapezoid_layers**. In V5, there are 9 such layers corresponding to the 9 trapezoidal retrieval functions utilized for O_3.

Carbon Monoxide Trapezoidal Profile

See the discussion in the section, "Trapezoidal Layers", above. Replace XX with CO in that text.

The AIRS standard CO product is a product of the IR stage of the combined IR/MW retrieval. **CO_VMR_eff** is the retrieved volume mixing ratio (ratio of number of CO molecules to the number of molecules of air in a unit volume) for a layer defined by the faces of the CO trapezoidal retrieval function. The boundaries of the faces of these layers are specified in **CO_trapezoid_layers**. In V5, there are 9 such layers corresponding to the 9 trapezoidal retrieval functions utilized for CO.

Methane Trapezoidal Profile

See the discussion in the section, "Trapezoidal Layers", above. Replace XX with CH4 in that text.

The AIRS standard CH_4 product is a product of the IR stage of the combined IR/MW retrieval. **CH4_VMR_eff** is the retrieved volume mixing ratio (ratio of number of CH_4 molecules to the number of molecules of air in a unit volume) for a layer defined by the faces of the CH_4 trapezoidal retrieval function. The boundaries of the faces of these layers are specified in **CH4_trapezoid_layers**. In V5, there are 7 such layers corresponding to the 7 trapezoidal retrieval functions utilized for CH_4.